The Active Fracture Model and Fractal Flow Behavior

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RESEARCH OBJECTIVES

Continuum approaches are commonly used for modeling flow and transport in unsaturated fractured rocks. A traditional continuum approach assumes uniformly distributed flow patterns at a subgrid scale and therefore cannot be used for representing gravity-driven fingering flow and transport in fracture networks. In an effort to incorporate this figuring flow behavior into the continuum approach, Liu et al. (1998) developed the active fracture model (AFM), which assumes that only a portion of fractures in a connected unsaturated fracture network contributes to liquid water flow. The major objective of this work is to provide a further evaluation of the AFM, based on both theoretical arguments and field observations (Liu et al., 2003).

APPROACH

A flow system exhibits so-called fractal flow behavior when the corresponding flow patterns can be characterized by fractals. Many laboratory and field experiments have shown that complex fingering flow patterns in unsaturated porous media are fractal patterns. We used a box-counting approach to detect fractal flow patterns from spatial distributions within coated fractures (a sign of water flow within fractures) in the Yucca Mountain unsaturated zone (Figure 1). The theoretical relationship between the AFM and fractal flow patterns was also explored. AFM-based simulation results were then compared to C-14 and fracture coating data to check the validity of the AFM.

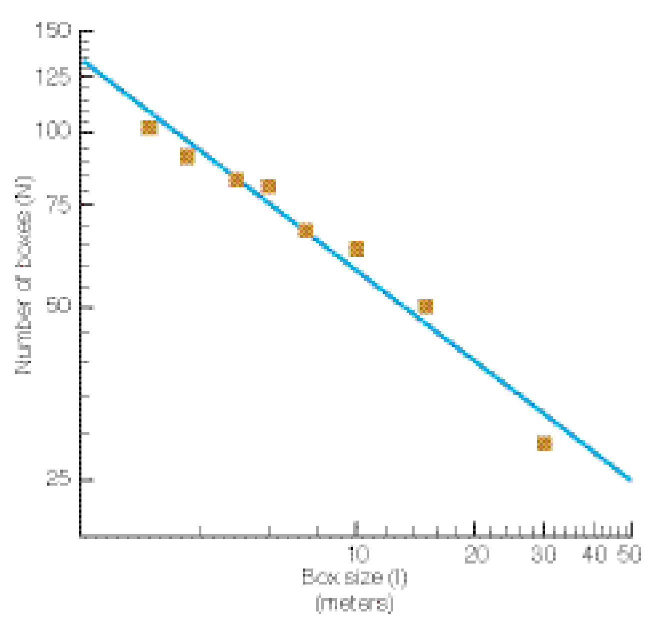

Figure 1. Relation between the number of boxes (N) covering at least one coated fracture, and box size l. The fitting of the solid line (corresponding to a power function) with the data points indicates a fractal pattern.

ACCOMPLISHMENTS

We demonstrated that flow patterns in unsaturated fractured rock, like those in unsaturated porous media, are fractal (Figure 1). While the AFM was initially developed as an empirical model, a rigorous theoretical relation between AFM and the fractal flow pattern was established. Comparisons between model simulations and the relevant field observations support the validity of the AFM.

SIGNIFICANCE OF FINDINGS

The inadequacy of numerical models in predicting fast flow and transport processes has been a significant problem for many unsaturated systems. In this work, we showed that complex unsaturated flow patterns in both porous media and fractured rock are fractal patterns, and that the AFM can capture this important behavior at the subgrid scale. Because of the relative simplicity of fractal-based characterizations, we believe that the fast flow behavior in unsaturated systems can be successfully captured by the improved large-scale continuum approach. This is partially supported by the consistency between simulation results based on the AFM and field observations from the Yucca Mountain unsaturated zone. Future work will focus on the possibility of extending the AFM to unsaturated porous media.

RELATED PUBLICATIONS

Liu, H. H., C. Doughty, and G. S. Bodvarsson, An active fracture model for unsaturated flow and transport in fractured rocks. Water Resour. Res., 34, 2633–2646, 1998.

Liu, H.H., G. Zhang, and G.S. Bodvarsson, The active fracture model: Its relation to fractal flow behavior and a further evaluation using field observations. Vadose Zone Journal, 2, 259–269, 2003.

ACKNOWLEDGMENTS

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